Risø energy report 9 : Non-fossil energy technologies in 2050 and beyond

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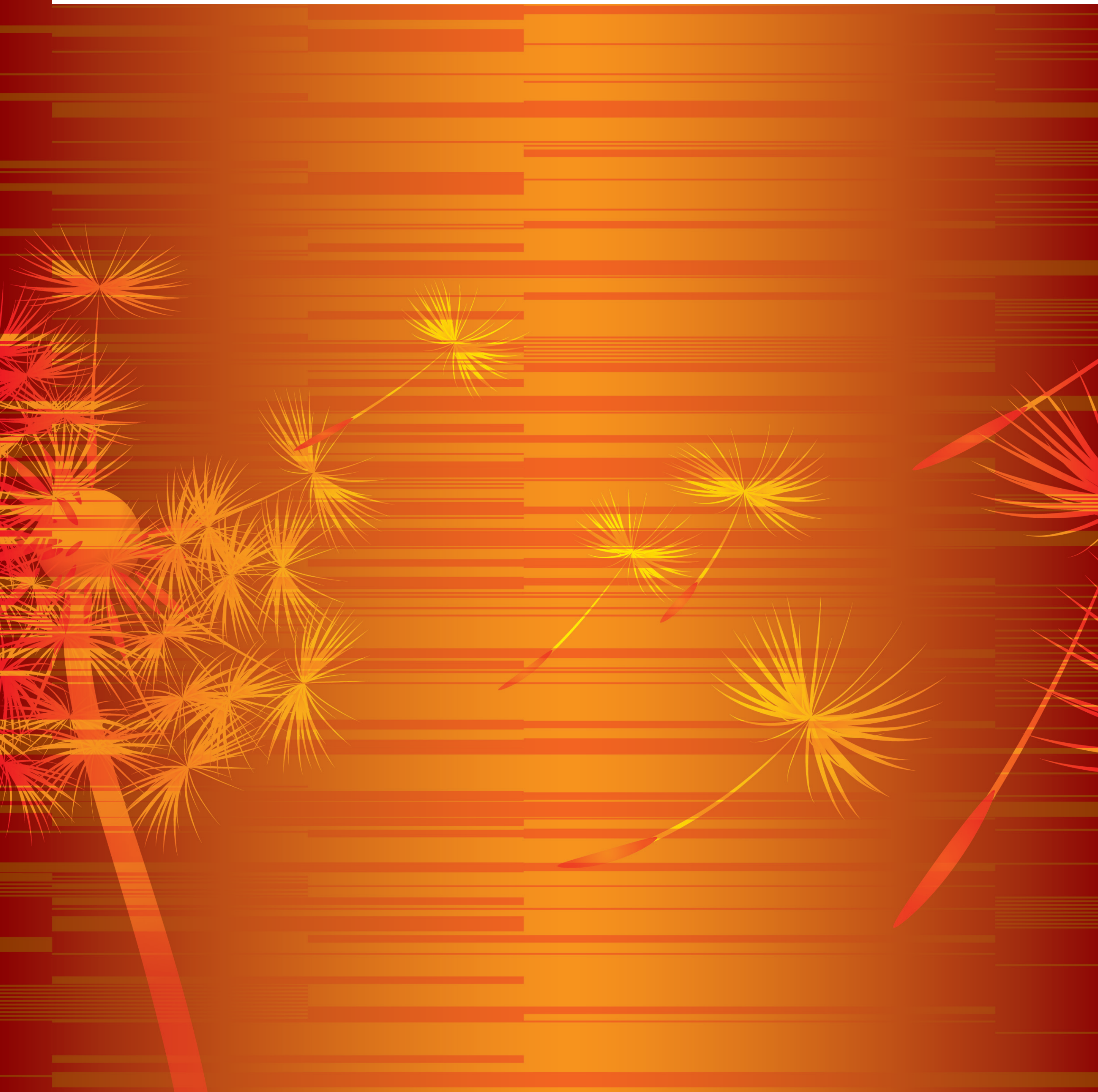
Risø Energy Report 9

Non-fossil energy technologies in 2050 and beyond

Reprint of summary and main conclusions

Risø-R-1729(EN) November 2010

Edited by Hans Larsen and Leif Sønderberg Petersen



Risø DTU
National Laboratory for Sustainable Energy

Risø Energy Report Series

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Edited by Hans Larsen and Leif Sønderberg Petersen
Risø National Laboratory, November 2006, 72 pp.
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Future options for energy technologies
Fossil fuels provide about 80% of global energy demand, and this will continue to be the situation for decades to come. In the European Community, we are facing two major energy challenges. The first is sustainability, and the second is security of supply, since Europe is becoming more dependent on imported fuels. These challenges are the starting point for the present Risø Energy Report 6.
Edited by Hans Larsen and Leif Sønderberg Petersen
Risø National Laboratory, November 2007, 84 pp.
ISBN 978-87-550-3611-6, Risø-R-1621(EN)

Risø Energy Report 7
Future low-carbon energy systems
The report presents state-of-the-art and development perspectives for energy supply technologies, new energy systems, end-use energy efficiency improvements and new policy measures. It also includes estimates of the CO_2 reduction potentials for different technologies. The technologies are characterized with regard to their ability to contribute either to ensuring a peak in CO_2 emissions within 10–15 years, or to long-term CO_2 reductions. The report outlines the current and likely future composition of energy systems in Denmark, and examines three groups of countries: i) Europe and the other OECD member nations; ii) large and rapidly growing developing economies, notably India and China; iii) typical least developed countries, such as many African nations. The report emphasises how future energy developments and systems might be composed in these three country groupings, and to what extent the different technologies might contribute.
Edited by Hans Larsen and Leif Sønderberg Petersen
Risø DTU, October 2008, 86 pp.
ISBN 978-87-550-3690-1, Risø-R-1651(EN)

Risø Energy Report 8
The intelligent energy system infrastructure for the future
The report takes its point of reference in the need for the development of a highly flexible and intelligent energy system infrastructure which facilitates the integration of substantially higher amounts of renewable energy than today's energy systems. This intelligent and flexible infrastructure is a prerequisite in achieving the goals set up by IPCC in 2007 on CO_2 reductions as well as ensuring the future security of energy supply in all regions of the world. The report presents a generic approach to future infrastructural issues on a local, regional and global scale with focus on the energy system. The report is based on chapters and updates from Risø Energy Report 1 – 7, as well as input from contributors to the DTU Climate Change Technology workshops and available international literature and reports.
Edited by Hans Larsen and Leif Sønderberg Petersen
Risø DTU, September 2009
ISBN 978-87-550-3755-7, 72 pp.
Risø-R-1695(EN)

Summary and main conclusions

Hans Larsen and Leif Sønderberg Petersen, Risø DTU, Denmark

Long-term energy security depends on the continuing availability of fossil fuels and their potential substitution by renewable energy sources. Coal and gas may well dominate the global primary energy supply for the rest of this century if no special effort is made to promote renewables. However, for many countries energy security concerns are accompanied by a preference for renewable options which can reduce their dependence on imported oil and gas, as well as helping to meet environmental policy objectives.

To keep the global mean temperature rise below 2°C we need, according to the IPCC, to reach global stabilisation at 450 ppm CO2eq, which means that global greenhouse gas (GHG) emissions must be halved by 2050 and in fact reduced even more in the OECD countries.

According to the analyses presented in this report, it will be difficult for the European countries to meet these targets as mitigation options from the energy sector alone do not seem to be sufficient, but have to be supplemented by action from other sectors, for example the agricultural sector.

On the other hand, the Danish case described in this report shows that Denmark stands a good chance of meeting the mitigation goals and of being able to phase out fossil fuels rapidly and thus reduce GHG emissions at the pace needed. Denmark's wind and biomass resources, in particular, would allow the phase-out of fossil fuels from the generation of electricity and heat before 2040. Removing fossil fuels from the transport sector will probably take another 10 years.

Renewable energy technologies

Solar energy can be used to generate heat and electricity all over the world. Our technical ability to exploit this resource has improved dramatically in recent years, and by 2050 the IEA forecasts that the PV and CSP technologies will each produce 11% of the world's electricity.

PV is by nature a distributed generation technology, whereas CSP is a centralised technology, so their deployment will follow very different routes. PV is unique among electricity generation technologies in that its distributed nature allows it to be integrated with human settlements of all sizes, urban or rural.

Since 1970, wind energy has grown at spectacular rates, and in the past 25 years global wind energy capacity has doubled every three years. The current wind energy capacity of approximately 160 GW is expected to generate more than 331 TWh in 2010, covering 1.6% of global electricity consumption.

Most of the development effort so far has been dedicated to the evolutionary scale-up and optimisation of the land-based three-bladed standard wind turbines which emerged as commercial products at the beginning of the 1980s.
The coming decade may see new technological advances and further scale-up, leading to more cost-effective, reliable and controllable wind turbines and new offshore and onshore applications, including the introduction of wind power in the built environment. With increased focus on offshore deployment combined with the radically different conditions compared to onshore, it is likely that completely new concepts will emerge, such as the vertical-axis turbine currently being developed at Risø DTU. Wind energy has the potential to play a major role in tomorrow's energy supply, cost-effectively covering 30-50% of our electricity consumption.

Hydropower is a mature technology close to the limit of efficiency, in which most components have been tested and optimised over many years.

Wave energy can be seen as stored wind energy, and could therefore form an interesting partnership with wind energy. Globally, the potential for wave power is at least 10% of total electricity consumption, or more if we tolerate higher prices. An ambitious yet realistic goal for Danish wave power by 2050 could be around 5% of electricity consumption.

Biomass presently covers approximately 10% of the world's energy consumption. A realistic estimate of the total sustainable biomass potential in 2050 is 200-500 EJ/yr covering up to half of the world's energy needs in 2050.

A large proportion of biomass will probably still be in the form of wood for direct burning in less developed areas of the world. Biomass plays a special role as an easily storable form of energy, in CHP systems based on sophisticated combustion technologies and as a source of liquid fuels for transport.

Several technologies are currently being developed with a view to improving biomass use, and these will help to make bioenergy competitive when oil prices increase. Biomass is a limited resource, and increases in biomass production should preferably not compete with the food supply.

Geothermal energy is used in two ways: At least 24 countries produce electricity from geothermal energy, while 76 countries use geothermal energy directly for heating and cooling. In 2008, the global production of geothermal heat

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was 0.2 EJ, with 10 GW of installed baseload electricity production capacity.

The potential for the future is huge. According to estimates by the International Energy Agency, the most probable potential for the global geothermal resource is approximately 200 EJ/yr, including 65 EJ/yr from electricity production.

In Denmark, the potential for geothermal energy is substantial since suitable aquifers are available, and the technology is an excellent match for the district heating systems already widely used. Geothermal energy is therefore expected to cover a large part of the demand for future district heating. The Greater Copenhagen area has enough geothermal reserves to meet all its needs for heat for thousands of years.

To date, R&D work on energy storage has focused on electricity, as electricity storage has an obvious, straightforward and urgent role in the energy market. Many types of electricity storage will be of great importance in the coming decades.

A shift to sustainable energy sources will also require mobile storage technologies for vehicles. Capturing electricity from wind and solar sources in a concentrated form, these will need to deliver driving ranges similar to those of modern gasoline and diesel vehicles.

In future storing energy as hydrocarbons synthesised from hydrogen, made by the electrolysis of water, and carbon dioxide extracted from the atmosphere may become viable. The distribution system for liquid fuels is in place, so synthetic liquid fuels will not require huge investments in new distribution systems.

There is also considerable technical and economic potential for heat storage. Energy storage has enormous technical potential, and it is likely to appear in many different guises among the building blocks of a future sustainable energy system. However, the costs associated with storing energy are often considerable and sometimes prohibitive.

Nuclear fission is a proven technology, but its exploitation has grown only slowly in the past 30 years. However, the need for an energy supply with low fossil fuel dependence and low greenhouse gas emissions has led to renewed interest in nuclear energy. Many countries now plan to adopt or expand their use of nuclear fission. In total, nuclear provides 14% of the world's electricity consumption, though this figure has fallen slightly in recent years.

USA expects a nuclear renaissance, and China, India and Russia have even more ambitious plans for expanding nuclear power by 2030 through the installation of 100, 60 and 20 GWe, respectively. Based on existing plans, world nuclear capacity may therefore increase from its present 340 GWe to more than 1,000 GWe in 2050, increasing nuclear's share of the electricity supply to 20%. The next generation of nuclear energy systems, Generation IV, may be deployed from 2040 onwards. Generation IV systems include fast-neutron breeder reactors, allowing for a much improved utilisation of uranium and thorium resources and a reduction of the radioactive waste. The reactors have higher operating temperatures, which opens up for new applications of nuclear energy, such as the production of liquid chemical fuels and thermo-chemical hydrogen production. Fusion research is now taking the next step with the construction of ITER. Expected to start operating in 2020, ITER will demonstrate self-sustaining controlled fusion for the first time by 2026. Building on experience gained from ITER, plans are to build the future DEMO facility in 2030-2040 and for it to operate during 2040-2050, generating several hundreds of megawatts for extended periods of time. DEMO will also test and qualify key components under realistic operating conditions. If everything goes according to plan, the first commercial fusion power plant will then be commissioned by 2050.

Carbon capture and storage (CCS) can be used on large point sources based on fossil fuels such as power plants and industrial furnaces. The technology can be retrofitted at existing combustion plants without major changes, but running costs are rather high.

The main cost of CCS relates to the CO_2 capture stage, in terms of both its capital cost and the loss in efficiency at the power plant to which it is fitted.

To improve the chances of meeting the targets for CO_2 reduction, CCS should be used worldwide, and the building of full-scale demonstration plants must be accelerated to drive down costs. Proven fossil fuel reserves, especially coal, will last far beyond this century. With CCS we can continue to burn fossil fuels even in a carbon-neutral future. Later, CCS can even be used with biomass-fired power plants to create net negative CO_2 emissions.

System aspects

It will not be possible to develop the energy systems of the future simply by improving the components of existing systems. Instead, we need an integrated approach that will optimise the entire system, from energy production, through conversion to an energy carrier, energy transport and distribution, and efficient end-use.

Similarly, significant reductions in primary energy consumption will not be reached through evolutionary development of existing systems. This will require paradigm shifts and revolutionary changes, such as the automatic adaptation of consumption to match the instantaneous availability of all forms of energy.

There is also a need for a smart grid which will link production and end-use at the local level. End-users must help to maintain balance in the future energy system. New end-use technologies have to be widely introduced, including highly insulated, almost self-sufficient houses, smart electronic equipment, energy storage and local energy supplies such as heat pumps. Information and communications technology (ICT) will be very important to the successful integration of renewables in the grid.

Electric supergrids based on high-voltage direct current (HVDC) technology are promising because they offer the controllability needed to handle wind power effectively as well as efficient transport of electricity over long distances, even between different synchronous zones. Compared to other energy distribution systems, power grids are particularly vulnerable to disturbances and accidents. Today, the welfare gains are too insignificant to motivate end-users, because in most countries the production cost of electricity is small compared to the fixed added taxes and tariffs. Switching to value added taxes, grid payments which vary according to the grid load, and variable tariffs and taxes could stimulate flexible demand and "demand shifting".

Main conclusions

By 2050, the sum of the potential of all the low-carbon energy sources exceeds the expected demand. The challenge for a sustainable global energy system with low CO_2 emissions by 2050 is therefore to utilise this potential in the energy system to the extent that it can be done in an economically attractive way.

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Several energy supply technologies with low or even zero GHG emissions are already available on the market or will be commercialised in the decades ahead.

A future intelligent power system requires investment now, since uncertainty among investors is already hindering progress towards a higher share of renewable energy. If we do not make this investment, future generations may look back in disbelief that for so long we tolerated an antiquated energy system without putting in place the improvements that were already possible.

Developments in non-fossil energy technologies 2010 - 2050